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ECL 277

AN APPLICATION OF A STEEL STUB-GIRDER SUPERSTRUCTURE

Advantages and disadvantages of using this relatively new steel/concrete composite system are examined. Construction management issues include a jumpform system, typical floor slab reinforcing, shoring requirements, location of shear studs, and integration of the mechanical and electrical systems into the ceiling sandwich.

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AN APPLICATION OF A STEEL STUB-GIRDER SUPERSTRUCTURE

In the summer of 1992, Phase I of One London Place neared completion. Built by Sifton Properties Limited (Sifton) and co-owned by Sifton and London Life Insurance Company, One London Place was a twin tower office development located in downtown London, Ontario. The owners hired an independent design/consultant team to design the projcct. Phase I involved the construction of the first 24-storey tower using a steel stub-girder superstructure. The stub-girder system created some obstacles that Sifton had to overcome, such as the location of the header trench ducts and integration of the mechanical/electrical system into the ceiling sandwich. Consequently, Doug Smith, Sifton's project manager for One London Place, wondered about the feasibility of using a similar steel stub-girder system for the second 18-storey tower.

By August 1992, Phase I of One London Place was sixty percent leased. After the owners made the decision to proceed, Phase II would require approximately two years from the existing preliminary design to completion. Doug Smith thought that knowledge gained from Tower One would be an asset to the structural design of the second tower. Depending on market conditions, a decision by Sifton on the composition of the superstructure for the second tower could be required in the near future.

SIFTON PROPERTIES LIMITED

Sifton Properties Limited, a family-owned building and development company, had been involved in residential and commercial construction projects in southwestern Ontario for over seventy years. Started by Harry L. Sifton in 1922, the small, London, Ontario home construction business had blossomed into a full-fledged development firm by the early 1990s. The company grew and rapidly established a reputation as a builder of quality residential housing. For the last two decades, Sifton's building and development base has expanded to other major Ontario centres, making Sifton one of the largest diversified firms of its type in southwestern Ontario.

Sifton had built several large commercial and residential construction projects. A major addition to Westmount Shopping Centre, completed in March 1989 in London; Waterpark Place, a twin tower high-rise condominium project completed in October 1990 in nearby Waterloo; and Sir Adam Beck, a luxury condominium project in London, demonstrated the magnitude and diversity of Sifton. Seven major office buildings in downtown London were owned and managed by Sifton. In the early stages of company development, the Industrial and Commercial Division of Sifton hired and managed independent builders to construct its projects. As the company evolved, Sifton made the transition to building its own major high-rise commercial projects. One London Place was the first high-rise commercial office building developed and constructed by Sifton.

Doug Smith was hired as the project manager and a project management team was assembled using qualified Sifton personnel to build One London Place. The project management team for One London Place consisted of a project manager, an architectural/structural coordinator, a mechanical/electrical coordinator, a materials/scheduling coordinator, a document control supervisor, and a hardware coordinator/receptionist. The team was assembled by Sifton after Phase I had been designed and sub-grade construction had begun.

ONE LONDON PLACE

Located at the southwest corner of Queens Avenue and Wellington Street in London (Exhibit 1), One London Place was targeted to become one of the city's most prestigious office buildings. Two key factors were used to attract tenants. First, a superior mechanical/electrical/communication system provided ultimate control, flexibility, and comfort to individual office spaces. Second, exceptional flexibility was provided for office layouts. Flexibility for office layouts (Exhibit 2) was achieved by an in-floor electrical and communications distribution system, a flexible lighting grid, long span beams, and 2'- 6"[1], rather than 5'- 0", spacing of window mullions. One London Place, at 365 feet above grade, was the tallest office building in downtown London. Phase I was a 24-storey, 400,000 square foot post-modern office building with a silver-glazed facade and an Atlantic blue granite base. Considerable attention was devoted to the lobby. A unique, prestigious look was created by using only the finest materials such as a polished marble floor, walls clad in marble and granite, and a 35 foot high vaulted ceiling (Exhibit 3). The five level, underground, 735 vehicle parking garage was the deepest parking structure in London and met the parking requirements for both towers. A circular service bay was located at the rear of the Phase I tower.

Phase II would consist of a second, 18-storey high-rise similar to the first tower in plan and facade, providing an additional 250,000 square feet of leasable office area (Exhibit 4). The two towers would be joined by a 65 foot tall all-glass vaulted atrium. A picturesque plaza with a fountain, benches, elegant lamps, and granite paved, tree-lined walkways would provide an inviting street level entry to the twin tower complex.

[1] One London Place was built using Imperial as the main system of measurement, although some materials and/or components were manufactured to metric specifications.

The foundation of One London Place was constructed of reinforced concrete grade beams and a concrete foundation wall. Both were supported on reinforced concrete caissons, which varied in diameter from 3 to 10 feet, bearing on a till layer which varied in depth from 64'- 6" to 71'- 6" below street level. The total site perimeter incorporated a continuous 36-inch diameter interlocking-caisson system with soldier piles and anchor tie backs located at every third caisson. This caisson wall formed a shoring/water barrier system which permitted excavation, allowed sub-grade construction, and prevented water seepage into the underground parking structure. Phase I included all sub-grade provisions for the second tower.

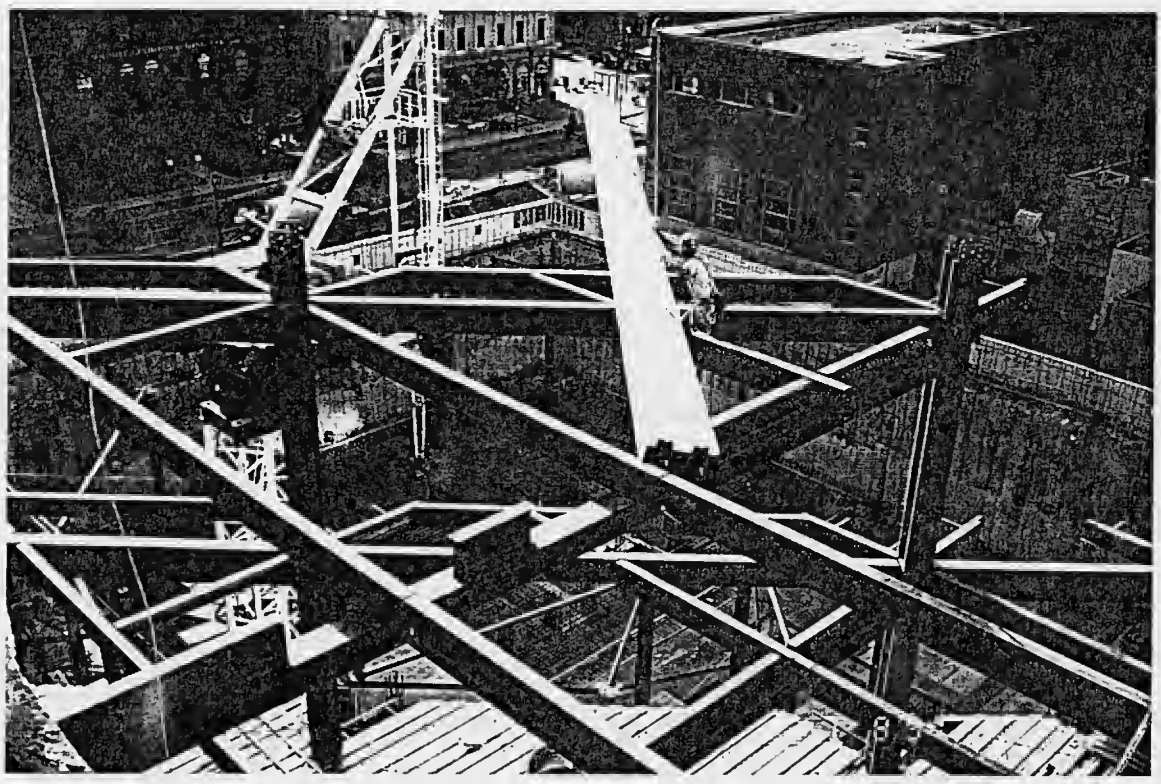

Figure 1: Photograph of the structural steel stub-girder system

The superstructure of the 24-storey office tower was a structural steel stub-girder system (Figure 1). This system had been chosen to achieve long clear spans and accommodate the extra duct work in the ceiling sandwich as required by the extensive mechanical system. Despite several advantages, composite systems such as steel stub-girders were relatively new to the steel industry which caused problems.

SUPERSTRUCTURE - ONE LONDON PLACE, PHASE I

Doug Smith had considerable experience in the construction industry. Projects he had worked on previously varied from low level industrial buildings to multi-story office

buildings. Prior to becoming the project manager at One London Place, Doug had been the assistant project manager for the construction of a $160 million automotive plant in Ingersoll, Ontario. Each construction job Doug worked on presented new difficulties, but he found that the construction management and problem solving skills he had acquired could be applied to each job. Despite the fact that Doug had worked for many years in the construction industry, One London Place was his first project using a stub-girder system.

During construction of the steel stub-girder superstructure of One London Place, many subtrades were working in close proximity which required careful coordination between the project management and construction teams. Doug re-examined a number of events affecting construction of the superstructure of Phase I. Several important factors he reviewed included:

a) finalization of structural details
b) in-floor electrical/communication distribution system
c) integration of the mechanical/electrical system into the ceiling sandwich
d) use of a jumpform system
e) location of the shear studs
f) typical floor slab reinforcing; shoring requirements; beam camber

<u>a) Finalization of structural details</u>
Some details for the structural steel were still being developed at the time contracts were being issued to major subtrades. Modifications and additions to drawings and/or specifications had a ripple effect. Virtually every subtrade felt the impact. The corrections and difficulties that resulted from these changes consumed a considerable amount of the project management team's time. Experience had prepared Doug for this, and he found effective ways to solve the problems. Doug knew that using any new type of construction guaranteed a distinct set of obstacles to be overcome. He thought practical knowledge gained on the steel stub-girder superstructure at One London Place by the both the design/consultant and project management teams could be a great asset in the design of Phase II.

<u>b) In-floor electrical/communication distribution system</u>
The office tower used a superior heating, ventilating, and air conditioning (HVAC) system, capable of providing 28 individually variable temperature zones on each floor. An in-floor electrical and communication distribution system allowed almost limitless access to electrical, telephone, and computer lines (<u>Figure 2</u>). Two main header trench ducts ran east-west, parallel to the long sides of the core and perpendicular to the stub girders. The centre line of these header trenches was 1'- 6" from the outside face of the core wall on the third floor and located in the same location on each subsequent floor. These ducts were used to feed power to the surrounding office space in a 4 foot by 5 foot grid system. A cellular flute arrangement was installed in the metal deck in the fabrication shop prior to being transported to the jobsite, making on-site location and placement of the preset inserts quick and simple.

Layout and placement of the components of the outer portion of the electrical and communication grid system required more labour than a normal deck slab for preparation, but did not create problems. In contrast, the location of the header trench ducts did create problems. As the live and dead loads decreased progressively from the bottom to the top of the structure, the core wall decreased in thickness a total of 10". However, the location of the header trench ducts remained in the same location from the inside face of the shaft wall floor to floor. This caused interferences with the stub-girder system which Doug and his mechanical/electrical coordinator had to deal with.

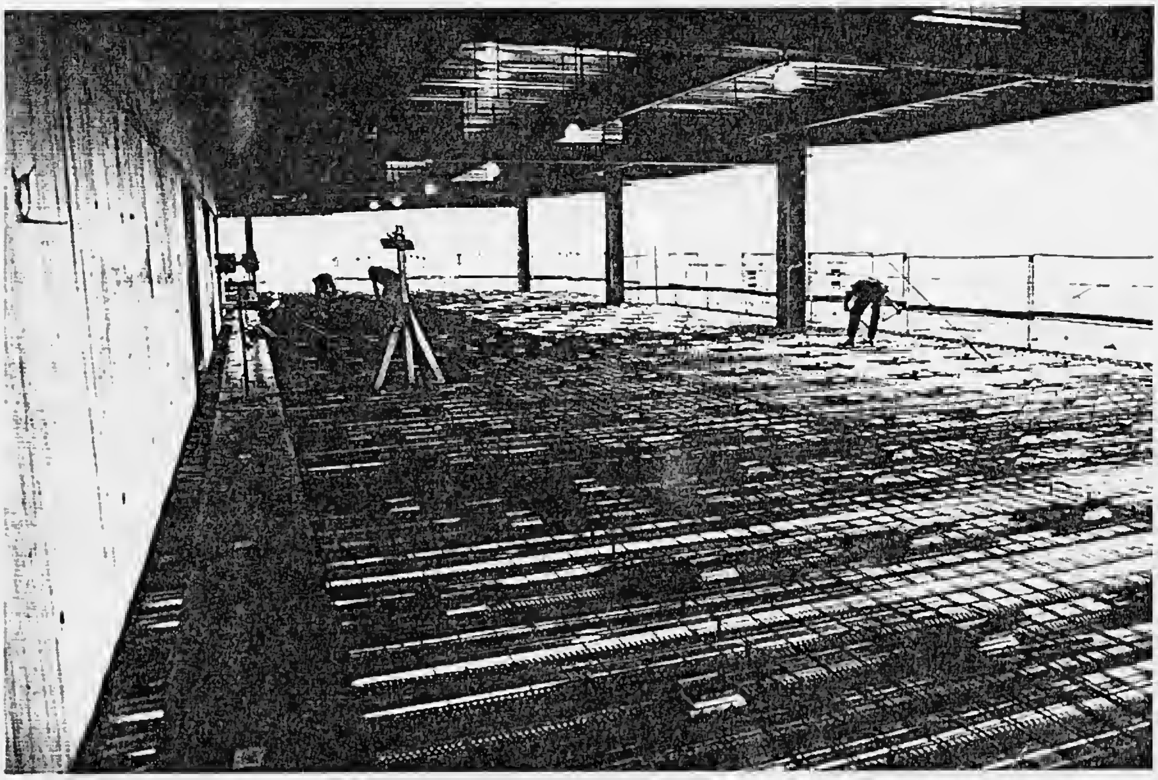

Figure 2: Photograph of the in-floor electrical/communication distribution system Note the header trench duct running parallel to the core on the left side of the photo.

c) Integration of the mechanical/electrical system into the ceiling sandwich

One major reason for using a stub-girder system at One London Place was to provide adequate working space and clearance for the extensive mechanical/electrical system in the ceiling sandwich. Ductwork running perpendicular to the stub-girders could run through the intermittent openings (Figure 3), reducing both interferences and the height of the ceiling sandwich. The number of system components required to meet the specifications of the mechanical/electrical system were approximately double the quantity normally required for a conventional system in an office building of equivalent square footage. To eliminate interferences on site, mechanical, electrical, and structural interference drawings were

produced by appropriate subtrades to identify potential conflicts. Using information from the interference drawings, design changes were made before construction in the ceiling sandwich began.

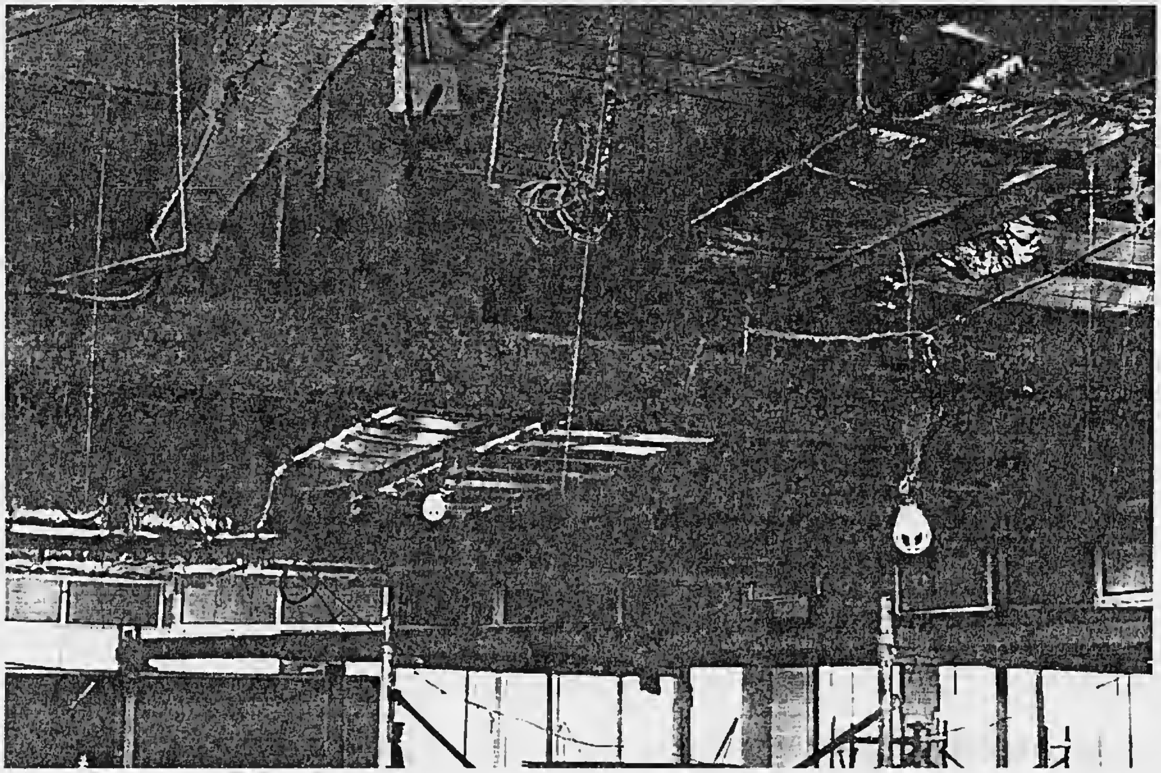

Figure 3: Photograph of mechanical ductwork running through a typical stub-girder

The owners wanted to maximize the floor to ceiling height as an important selling feature of the prestigious office space. To maintain a 8'- 9" ceiling height, the mechanical and electrical subcontractors had to work with extremely tight tolerances between components in the ceiling sandwich. Even two or three 1/4" errors in clearance, which were within acceptable industry standards, could accumulate and create unforseen interferences. As a result, the electrical/mechanical subtrades had to re-fit and re-locate components several times producing scheduling delays. A tremendous amount of time and effort was required by the project management team and the subcontractors to solve these difficulties. In some cases, the ceiling space provided was not adequate, even with the extra intermittent openings provided by the steel stub-girder system. As he reviewed the mechanical/electrical integration in the ceiling sandwich, Doug realized that using the stub-girder system may not have met all the requirements as efficiently as anticipated.

d) Use of a jumpform system

To avoid additional costs, extra hoarding, and heating problems associated with construction during severe winter conditions, the construction schedule was accelerated in

July/August/September 1991. The use of a jumpform system (Figure 4) allowed the corewall to be poured quickly and at the same time it reduced the amount of crane time. Construction of the corewall advanced ahead of the below grade suspended slab and the exterior frame followed. The elevating corewall form advanced at a rate of five floors per two-week period and kept the corewall construction ahead of the above-grade structural framing. The structural framing progressed at an average rate of three floors per three week period. The area surrounding the core was used as a workplace for the entire construction process. A consistent, uninterrupted flow of work was established for structural steel, reinforcing, and forming crews (Exhibit 5). The use of a jumpform system for construction of the core at One London Place worked effectively and efficiently, and proved to be an asset in the erection of the steel stub-girder superstructure.

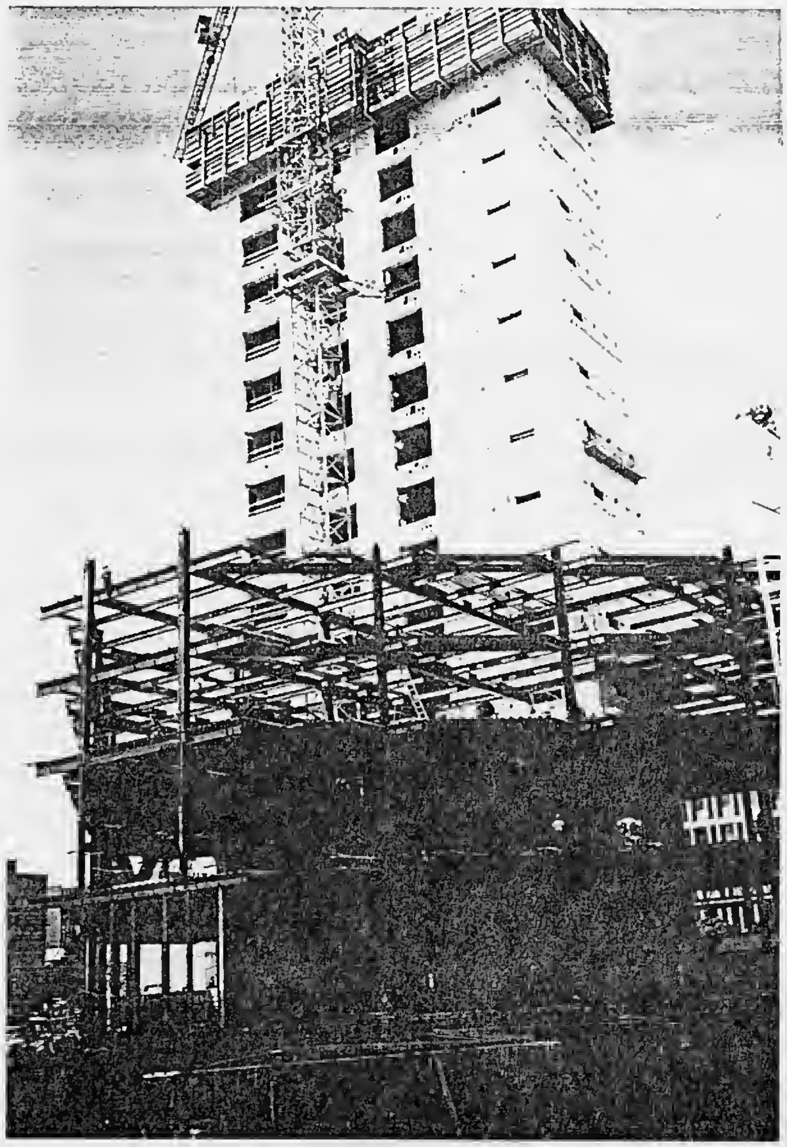

Figure 4: Photograph of the jumpform system.

e) Location of the shear studs

Shear studs are a vitally important part of a steel stub-girder system and provide a unique function not required in a normal steel/concrete deck system. In Phase I, the shear studs were welded to the top flange of the stubs and bccame embedded in the floor after the concrete slab was poured. On a typical stub-girder the shear studs (Figure 5) were spaced 3 3/4" laterally and the longitudinal spacing varied along the stubs. It was essential that the studs were located accurately which required an immense amount of layout time and demanded precision.

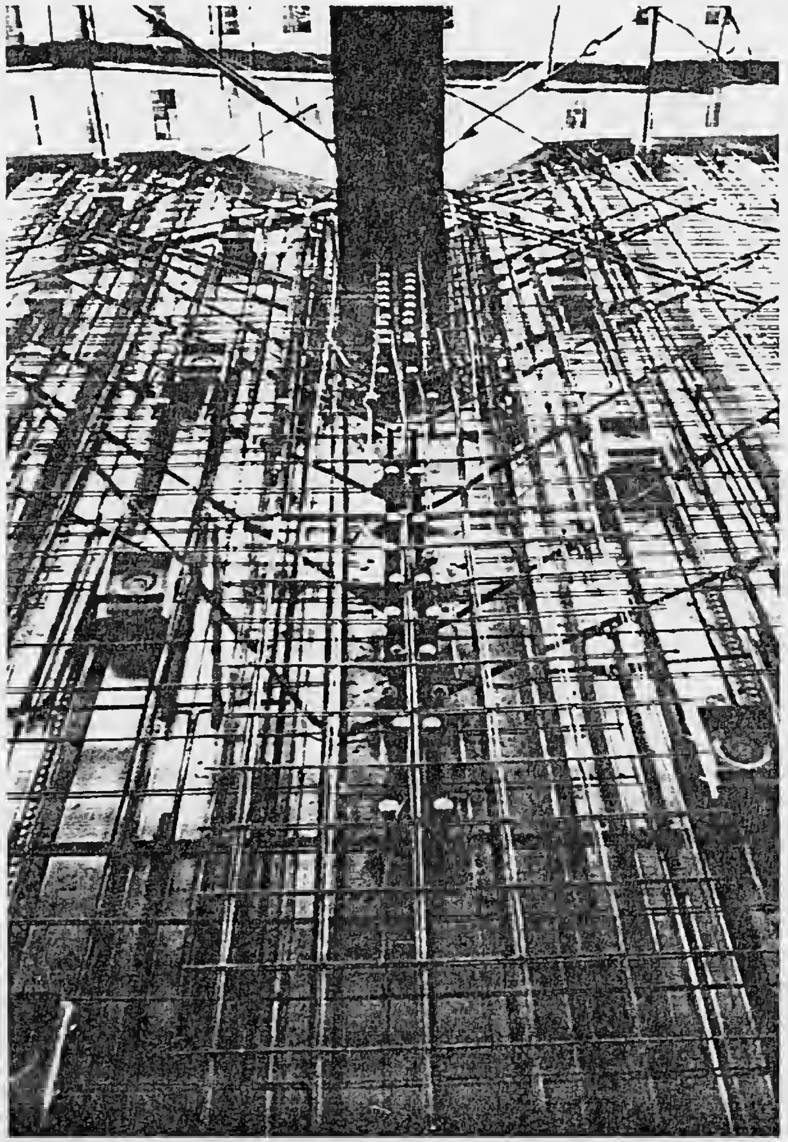

Figure 5: Photo of shear studs along a stub. Also note the herringbone shaped rebar.

The original structural specificátions/drawings specified the shear studs to be fastened through the metal deck with stud gun welds, directly on the top flange of the stubs.

Because of tight design clearances, and the need to avoid gaps and moisture between the metal deck and the stubs, the deck was field cut as necessary to facilitate proper control of the welding process. Cutting the deck required extra labour but ensured high quality stud welds. The task went smoothly once it was coordinated into the schedule.

f) Typical floor slab reinforcing; shoring requirements; beam camber

Placement of the reinforcing in the stub-girder system differed only slightly from a normal concrete deck-slab in that some herringbone shaped rebar was used to take the longitudinal stresses of the concrete deck-slab. This rebar was placed close to the ends of the stub-girders and around the exterior columns. Material handling and placing of the rebar was similar to that required for a normal system, but a nominal amount of extra effort was required to place the rebar around the closely spaced shear studs.

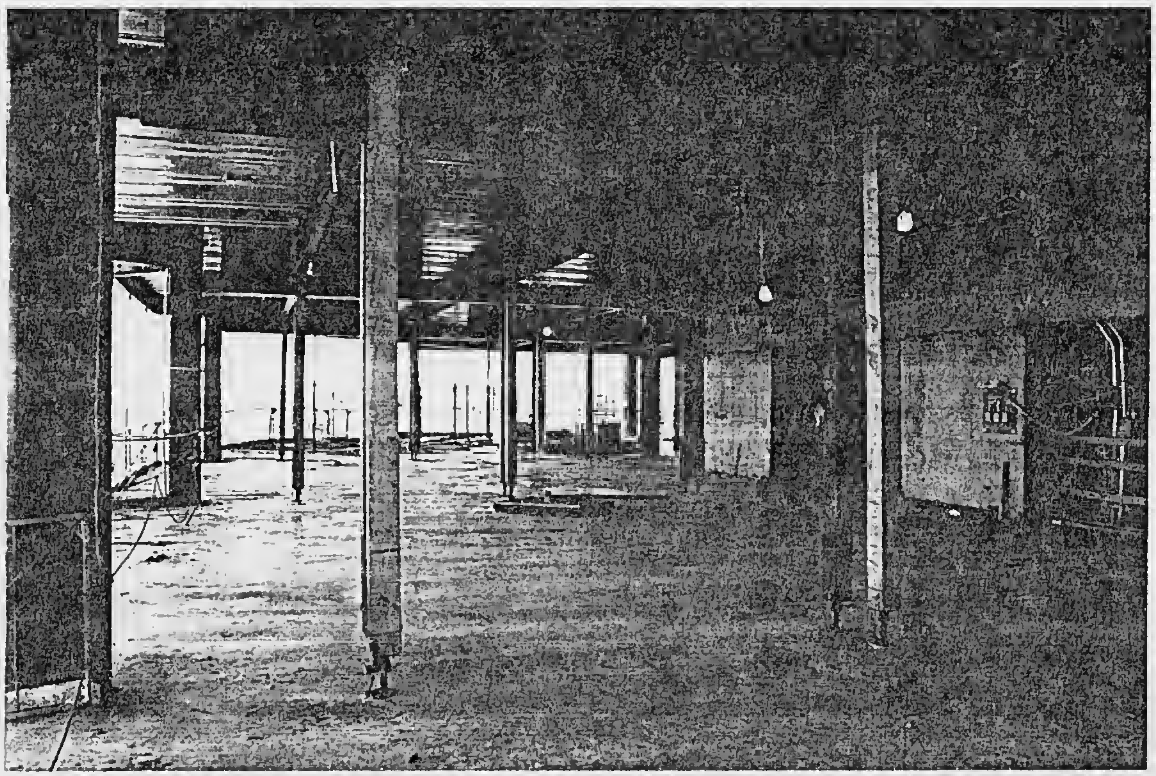

Figure 6: Photograph of the shoring used on a typical floor

During construction of the stub-girder system each floor had to be shored (Figure 6) for 3 weeks, give or take a few days due to temperature variations. Shoring remained in place until the concrete had cured and reached 75% of its design strength. Before the shoring could be installed, drawings showing size and location, had to be prepared and sealed by a professional engineer. Six inch square cedar shores, complete with screw jack adjustments, were installed in pairs at the intersection of the stub-girders and floor beams, and did not interrupt or interfere with the flow of work. Camber was shop fabricated in the beams

prior to being shipped to the jobsite; minor adjustments of the camber, if required, were done on the jobsite using the existing shoring. Having the camber shop fabricated was costly, but did eliminate the need for additional shoring.

Doug finished re-examining several important factors in the steel stub-girder system of Phase I. Numerous problems had been encountered and resolved. Doug knew knowledge acquired from Phase I could be applied in the design stage of Phase II, therefore, reducing the time spent modifying details during construction of the second tower. The in-floor electrical/communication system had caused interferences with the stub-girder system, but overall proved to be an efficient distribution system. The extensive mechanical/electrical system integrated into the ceiling sandwich required nearly double the number of components required in a normal system. Even with the extra intermittent openings provided by the stub-girders, interferences occurred and much time was spent resolving this construction problem. In contrast to this problem, Doug thought the jumpform system used to pour the corewall worked effectively and was problem free. Overcoming obstacles associated with welding the shear studs had proved to be a learning experience for several subtrades and Sifton itself. Learning gained in this area would help alleviate potential problems of this nature in Phase II. The shoring and herringbone shaped rebar required, although not typical to every steel structure, did not produce any problems.

Doug wanted to be totally prepared to provide accurate information from a construction point of view to the owners and design/consultant team if they had to make a decision in the near future on using a similar steel stub-girder superstructure for Phase II.

STUDENT ASSIGNMENT

Construction Management

1. As Doug Smith, project manager for One London Place, what recommendation(s) would you make to the design/consultant team regarding the feasibility of using a steel stub-girder superstructure for Phase II of One London Place?

2. What extraneous factor(s) could influence Doug's decision in Question 1?

3. Due to integration of the mechanical/electrical system into the structural stub-girder system, the ceiling sandwich is compacted causing a reduction in the floor to floor building height. If an 8" height reduction per floor occurred in a 24-storey office building, would the overall reduction be significant enough to affect the cost of the building (materials and/or labour)? Explain.

4. What subtrades would be on site at the time the case was being researched and written (August 1992)? List by description of work performed. **Hint:** not all subtrades are mentioned in the case study.

5. Following the service core forming, the exterior columns for the stub-girder system of One London Place, Phase I were erected in a 3 floor lift. Prepare a schedule that coordinates all the sub-trades required for the erection and installation of the stub-girder system for a 9 floor section of One London Place, Phase I.

6. The completion deadline for any construction project is always critical as delays can be costly and must be dealt with in an immediate and cost effective manner. List several events that could pose problems and/or delays in the schedule prepared in Question 4. Prepare 3 different plans to get a construction schedule back on track should any one of these events occur.

7. High early strength concrete cures more quickly than normal 25 MPa concrete. Jumpforms can be stripped the next day. Slabs can be stripped in 3 days when using high early strength concrete compared to 7 days for normal concrete. High early strength concrete costs $150 per cubic metre[2]; normal concrete costs $132 per cubic metre[2]. If One London Place used approximately 168 cubic metres of concrete per floor slab, would Doug Smith be able to justify the additional cost of using high early strength concrete to expedite the erection of the structure? Discuss the reasons for his decision.

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[2]Current (1993) price of concrete for a contractor. Excludes formwork and reinforcing; includes supply, placing, curing, and finishing.

8. On August 1, 1991, the Ministry of Labour passed a new safety regulation requiring that fall protection for iron workers must be used during all structural steel erection. This regulation was first proposed in May 1991, and relevant information was made available to the construction industry at that time. The fall protection regulation was passed after the structural steel for One London Place, Phase I was tendered and a contract awarded. An extra cost was claimed by the sub-contractor for the fall protection system required during structural steel erection. Would the sub-contractor be justified in billing Sifton for this extra cost? Why or why not?

9. Would the construction schedule prepared in Question 4 be possible without the use of a jumpform system? What are the differences between the jumpform and flying form (or handset) systems? How can these differences affect a construction schedule?

Structural Engineering

1. What creates the shear carried by the shear studs in the steel stub-girder system? How does this differ from a normal structural steel/concrete deck system?

2. Explain the difference in the longitudinal spacing of the shear studs on the stub-girders. Lateral[3] spacing of shear studs on a stub-girder is determined by engineering design criteria. What functional considerations should be involved in determining the width of the top flange of the stub-girder? **Hint:** refer to W59 Guidelines. How could the flange size of the stub-girder control the type of weld (gun weld or stick weld) used to fasten the shear studs? Could the flange size of the stub-girder and type of weld affect the treatment of the metal deck? Explain.

3. The herringbone shaped rebar takes the longitudinal stresses of the concrete deck-slab. Explain what causes these stresses and how they differ from the stresses in a normal structural steel/concrete deck system.

4. Would the in-floor electrical header trench ducts in Phase I interfere with the stub-girder system. If so, why? How could this structural problem be overcome?

5. Compare shoring requirements for a steel stub-girder system and a normal structural steel/concrete deck system. How and why do they differ? What effect would camber have on the shoring requirements?

6. Explain how cantilever construction or secondary framing could affect a stub-girder system.

[3] The spacing of the studs perpendicular to the centre line of the beam. Do not consider extra studs required at the intersection of the floor beams.

Exhibit 1 - Schematic site plan of One London Place

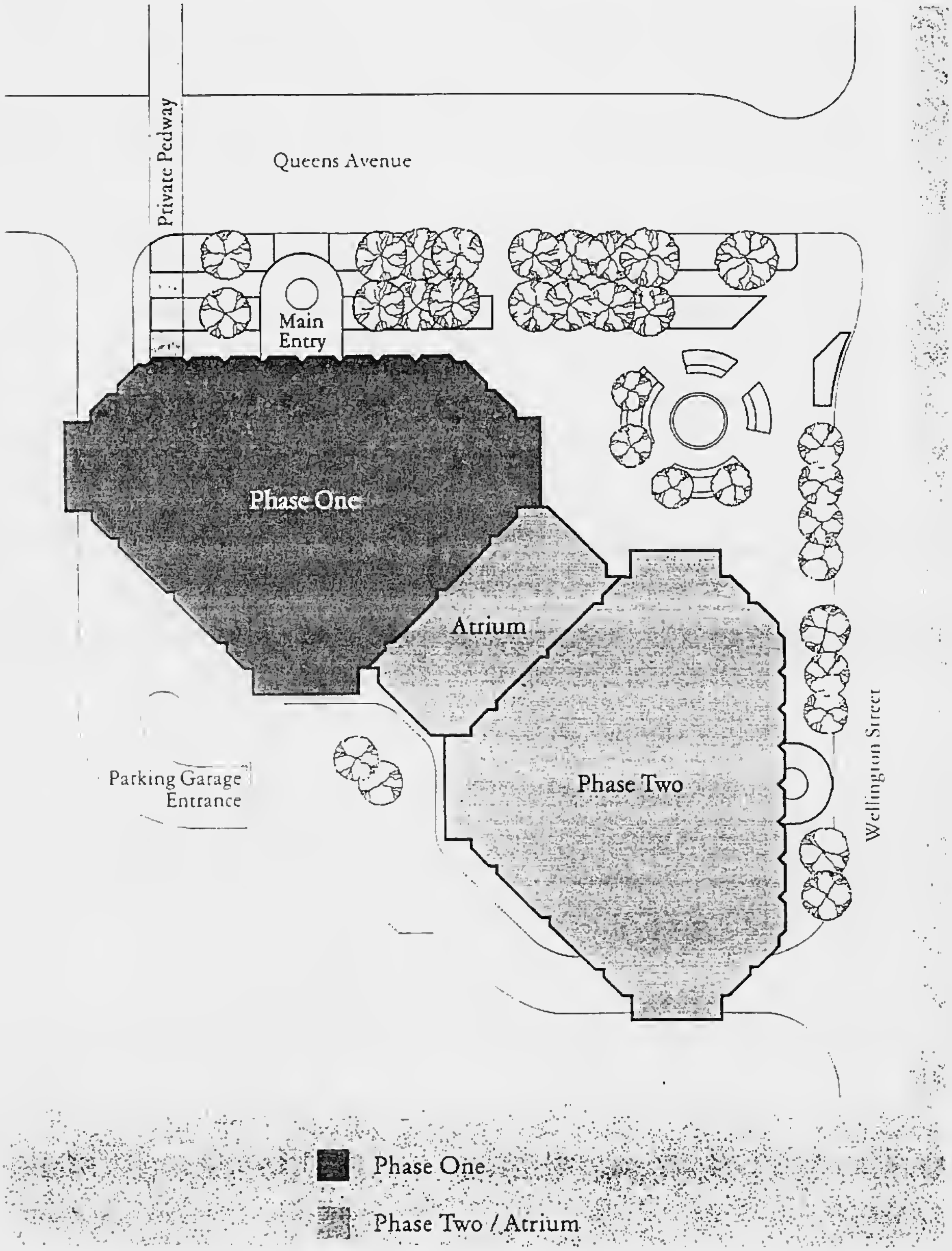
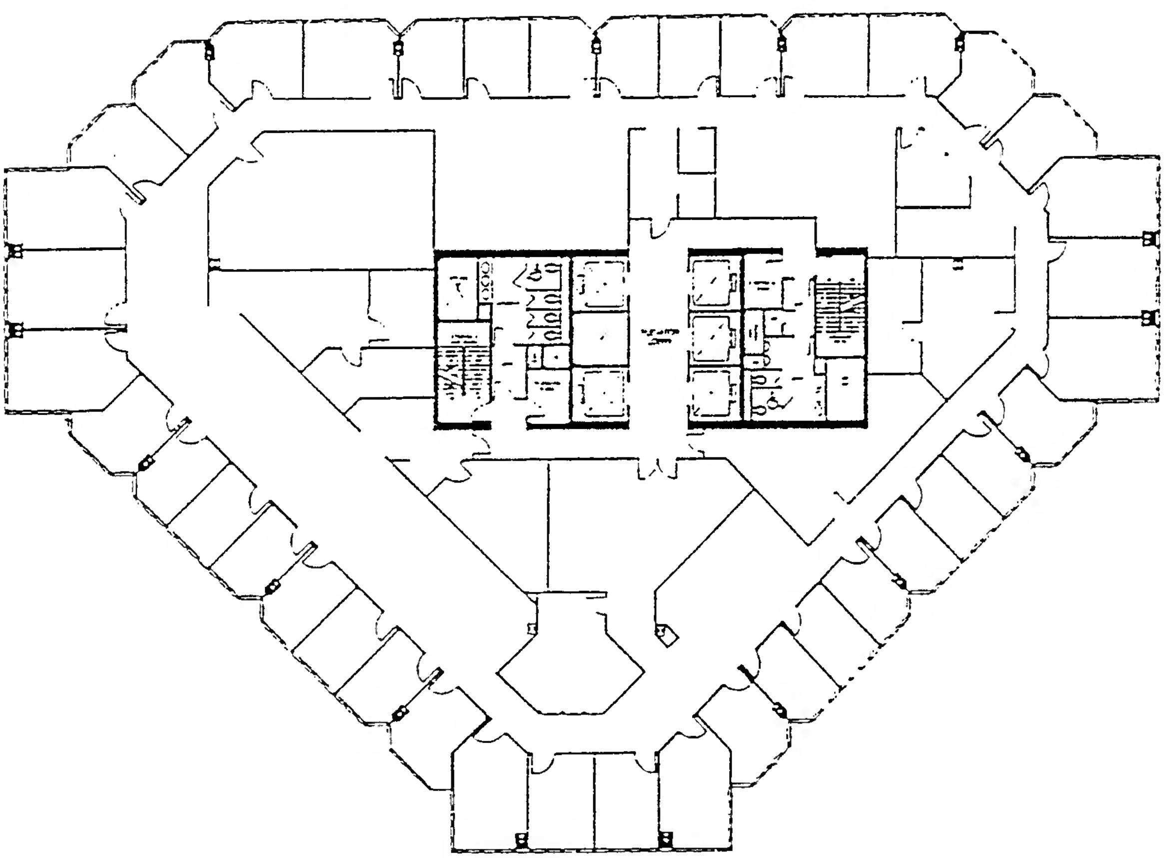


Exhibit 2 - Typical floor plan of Phase I with proposed office layout



TYPICAL FLOOR PLAN

Exhibit 3 - Rendering of the lobby of One London Place

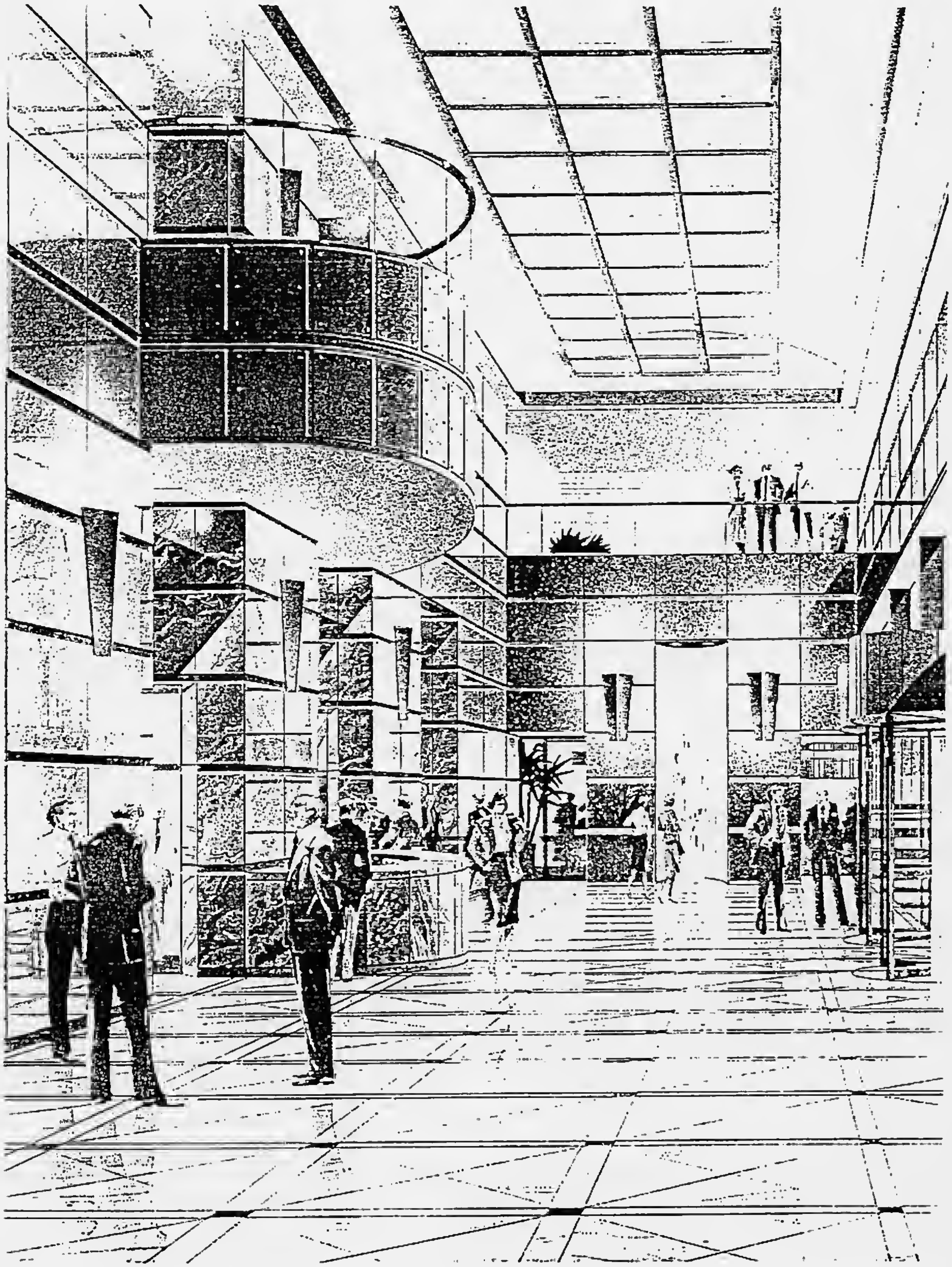


Exhibit 4 - Photograph of a Model of One London Place

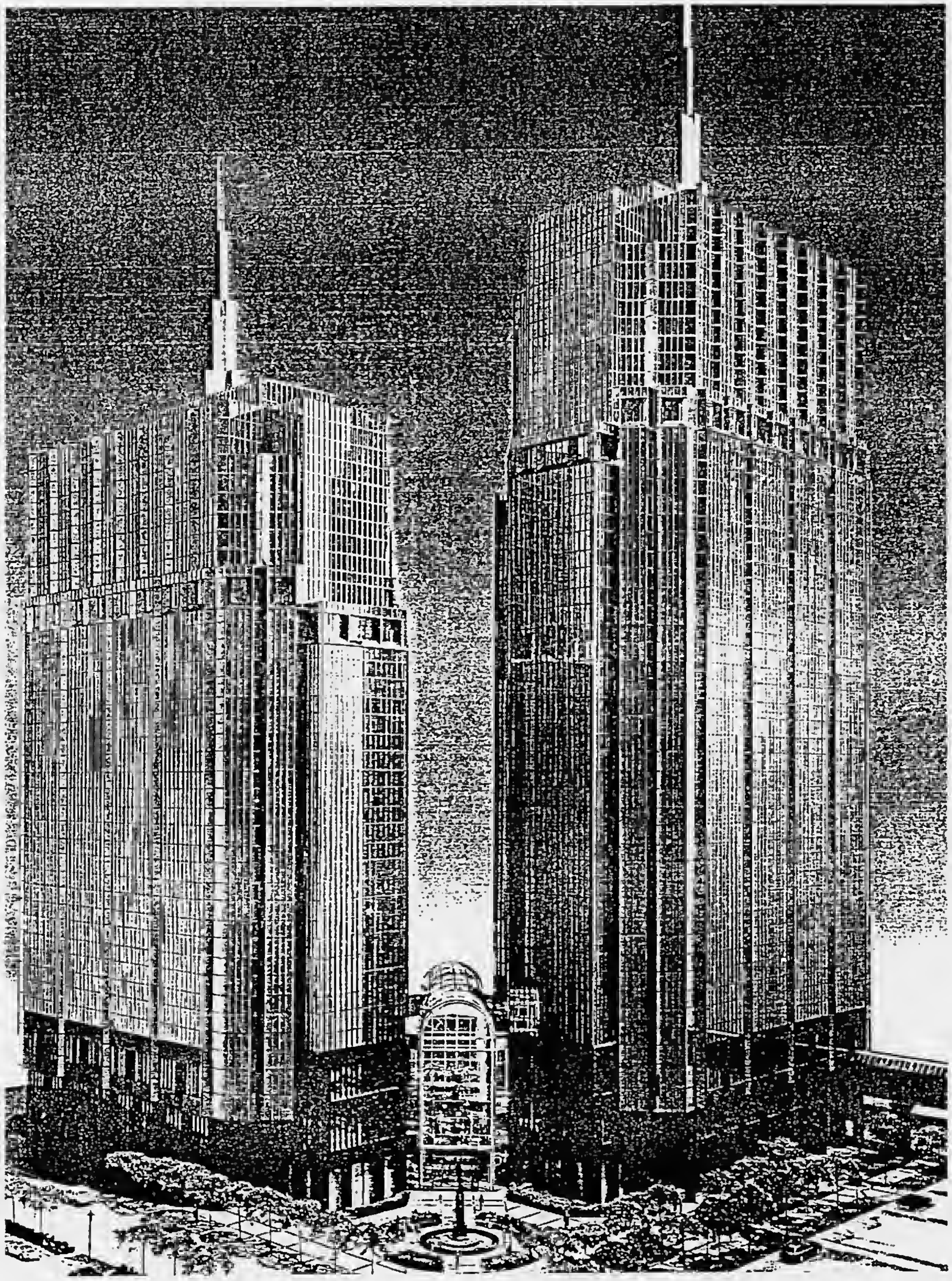
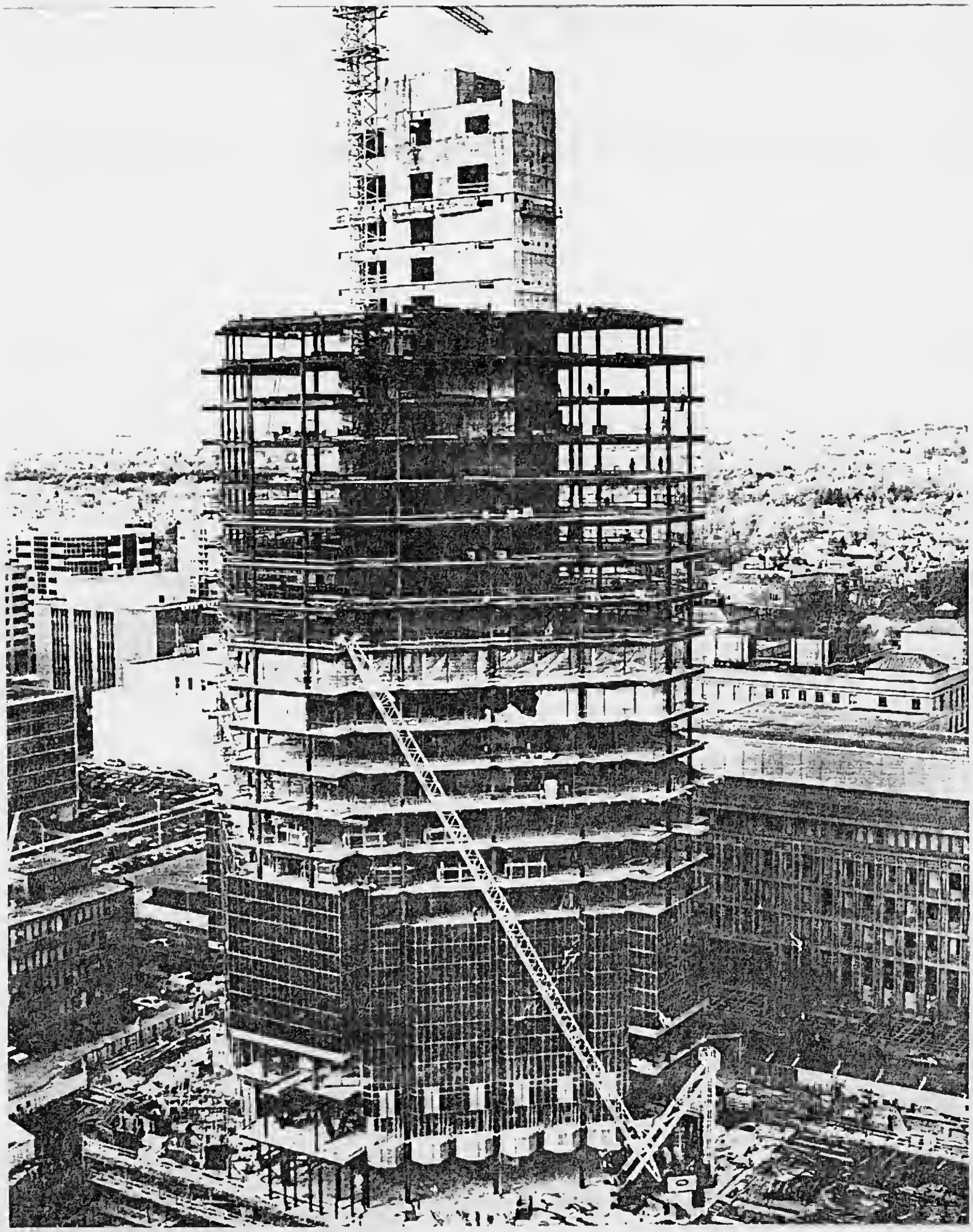


Exhibit 5 - Photograph of One London Place under construction in December 1991[4]



[4] Photograph provided complements of Victor Aziz Portrait and Commercial Photography, London, Ontario.

Anchor tie back - A cable anchored to a caisson, providing extra stability. The cable is installed in grout on an inclined plane. Occasionally tie backs are anchored into rock.

caisson - A watertight structure used to support the foundation of a structure below water.

camber - The slight curvature of a beam or deck. Camber can be induced (in the field or shop) in beams to compensate for deflection after the dead load has been applied.

cantilever - A beam or girder fixed a one end and free to move at the other end.

ceiling sandwich - Space between the underside of a floor (usually metal deck or poured-in-place concrete) and the underside of a ceiling (usually a suspended ceiling grid).

cellular flute arrangement - A structural metal deck which also is an electrical and telecommunications raceway.

central service core - The core in the centre of the building that contains the elevators, stairs, washrooms, mechanical and electrical shafts.

flying forms - Aluma trusses and plywood platforms specifically designed for segments of slab construction on reasonably typical floors.

foundation - Any part of a structure that transmits loads from a structure to the earth or rock below ground level.

foundation wall - The portion of the foundation for a building which forms a permanent retaining wall of the structure below grade.

girder - A large principle beam of steel, reinforced concrete, or timber which supports concentrated loads at isolated points along its length.

grade beam - The part of a foundation which supports the exterior wall of a superstructure, commonly designed as a beam bearing directly on column footings or caissons.

handset forms - Individual panels or scaffold frames commonly 'handset' as formwork for each concrete pour. Handset forms are similar to cribbing used in regular concrete forming, only on a much larger scale.

hoarding - A temporary board fence put around a building being erected or repaired. Can also refer to separation of one area from another by temporary tarps. Hoarding may be required to temporarily separate the public from an area, or enclose a building (or portion of a building) under construction to provide protection from the elements and a barrier for heat retention.

jumpform - A self elevating form wall which allows corewalls to be poured. After the form are in place, the corewall can then be poured by crane or by pumping of the concrete.

Upon completion of the pour, vertical members are removable for ease of stripping, elevating, and re-assembly.
mullions - A vertical member placed between the lights in a window or a door.

pile - A concrete, steel, or timber column which is driven into the soil to carry vertical loads or provide lateral support.

preset inserts - A device which locates the access to the electrical/telecommunication services in a predetermined grid base.

raceway - A channel for loosely holding electrical wires in a building.

secondary framing - Flexural members that are not part of a principle structural frame.

shoring - Pieces of timber or steel used to temporarily support a wall or floor system.

solider piles - A vertical member which takes the lateral thrust from the adjacent earth.

stick weld - (arc weld) The joining of metal parts by fusion. Heat is produced by electricity passing between an electrode and metal. The weld is accompanied by a metal filler rod with flux.

stub-girder - Short lengths of W-shape members connected intermittently to the top and bottom cord of a composite system to transfer the shear between the two elements.

stud gun weld - The process by which shear studs are fused to the stub-girder by using a timed, direct current arc type weld. A flash ring surrounds the base of the shear stud, controlling the rate of heat absorbtion and flash. A weld gun is used to produce heat by passing electricity between an electrode and metal.

subtrade(s) - A common name frequently used in industry referring to a sub contractor such as a structural, electrical, or roofing sub contactor.

superstructure - The portion of a building above the level of the ground or foundation which supports it.

trench header duct - The wiring raceway which feeds a cellular deck arrangement.

vierendeel girder - A girder which has a top flange and bottom flange with a discontinuous web joining the two components.